

Report to the
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Evidence for the
Domestication of
Chenopodium
In the Andes

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PURPOSE

The domesticated status of prehistoric assemblages of *Chenopodium* in the altiplano and intermontane valleys of South America has long been anticipated though not yet established. The purposes of this study are to determine when *Chenopodium* was domesticated in the Andean region and, if possible, to describe a time frame for the process of domestication. Was domestication of this plant resource a result of a precipitous morphological variation within the species or was it a slower, more gradual process?

THE QUESTION OF DOMESTICATION

The identification of prehistoric plant use and manipulation provides a great deal of information regarding the past ecological relationships between humans and plants. *Chenopodium* is said to have been cultivated in the altiplano and the intermontane valleys of South America millennia before the time of the Inka. Along with maize and potatoes, it was the principle food source of the ancient populations in the Andes (Soukup 1980-87).

By observing and comparing the morphology of ancient *Chenopodium* fruits with both modern wild *Chenopodium* and domesticated *Chenopodium*, specific differences in morphology which reflect human manipulation and domestication were investigated. This analysis is confined to the measurement and comparison of seed diameter and seed coat or testa thickness.

METHODS

Five modern *Chenopodium* species were chosen for examination and comparison with a number of prehistoric samples ranging in age from approximately 3000 B.C. to 1300 A.D.

Three modern domesticates from the Andes were selected, two of which are *Chenopodium quinoa*. One type was purchased at a local market in Jauja, Peru and the second was purchased at a market in La Paz, Bolivia. The third modern domesticate is *Chenopodium pallidicaule* whose common name is canihua and was purchased in Tiwanaku, a Bolivian village. Two modern wild species of *Chenopodium* were also collected from the Andes, *Chenopodium salinium* or quita quinoa and *Chenopodium ambrosioides* also called paiko.

MODERN DOMESTICATED CHENOPODS

Chenopodium quinoa, Jauja variety, "Jauja"
Chenopodium quinoa, Bolivian variety, "Bolivian"
Chenopodium pallidicaule, "canihua"

MODERN WILD CHENOPODS

Chenopodium salinium, "quita"
Chenopodium ambrosioides, "paiko"

Two hundred of each of the five modern varieties were measured under a light microscope using an ocular micrometer and their maximum diameters were recorded. (Figure 2 and Table I.)

INTERPRETATION OF SEED DIAMETER

Various scholars have suggested that the domesticated status of *Chenopodium* can be determined by analyzing maximum seed

diameter (Erickson in Pearsall 1980, Jones 1936, Pearsall 1989, 1989a, Browman 1986). This is based on the theory that seed size increases as a result of association with human use (Harlan 1975).

Seed size selection can occur for different reasons. Selective pressures associated with seedling competition and human intervention result in the planting and harvesting of seeds which are unlike their wild counterparts (Harlan 1975).

Schoenwetter (as quoted by Browman 1986, p. 145) reports that larger seeds are easier to harvest and store than smaller seeds. Smaller seeds are also reported to sprout earlier than larger seeds. If storage conditions are not ideal, small stored seeds may sprout prior to the sowing season thereby favoring large seeds for survival of storage. Planted fields would then be sown with the larger seeds that withstood the storage process. They, in turn, would produce large seeds which would also survive storage. Larger, more easily stored and sown seeds would be automatically selected early in the stages of domestication (Harlan 1975).

Because storage and sowing of seeds is an indicator of plant domestication, (Harlan 1975, Smith 1984) morphological changes in the fruit structure which favor storage situations might indicate selection and manipulation by humans for such qualities.

Planting techniques and customs will also affect seed size. Deep planting will select for large seeds where shallow planting selects for small seeds (Harlan 1975). Seed germination periods may also have an effect on human selection. Uniform maturation of either a wild stand or a sown field would create a manageable

cycle of planting, tending, harvesting and storage. This cycle is also considered to be a cultural hallmark of domestication as well as producing genetic changes within the plant population which distinguish it from wild populations (Harlan 1975).

There are other cultural factors which may have an impact on seed size selection. Cooking processes, including the availability of fuel, as well as selection for flavor may have an impact on seeds size preference (Harlan 1975). Whether seed size is associated with planting techniques or storage facilities, those seeds which adapt best to a habitat influenced by humans are favored.

In order to determine if an increased seed diameter is a morphological indicator of domestication in *Chenopodium*, seed diameters of modern wild and domesticated species of *Chenopodium* were compared with seed diameters of ancient *Chenopodium*, Figures 5 and 6. Since all the ancient seeds used in this analysis are carbonized, all modern seeds in this study were also carbonized.

LABORATORY CARBONIZATION OF MODERN VARIETIES

Seeds were carbonized using a Bunsen burner. Each of the five modern types were charred separately. There were 200 seeds from each group. In order to imitate the archaeological context in which *Chenopodium* seeds were initially carbonized, (Goette, et al 1990) the modern varieties were placed in a metal can on top of an inch of finely sifted sand. Three inches of sand were then layered over the seeds to prevent oxidation. The fruits were slowly burned at approximately 180 degrees Celsius. Every hour to

hour and a half, the seeds were removed from the heat to observe their condition. The seeds and sand were put through a geologic sieve to separate the sand from the seeds. The seeds and sand were then cooled for approximately fifteen minutes. If the seeds were not charred they were then returned with the sand to the Bunsen burner and the process was repeated.

Once the seeds appeared to be well parched, usually after about ten hours, the heat under the Bunsen burner was increased up to as much as 280 degrees Celsius. The cycle of heating and cooling was maintained in order to replicate what might occur in a domestic hearth with its constant intervals of heating and cooling as opposed to a sudden conflagration (Goette, et al 1990). Though the carbonization process varied from sample to sample, the average time for complete carbonization was twenty hours. An attempt to keep the temperatures at a moderate level was made in order to avoid undue distortion.

When the seeds were completely carbonized the seed diameter was again measured to see if seed size is influenced by carbonization. Bruce Smith (Smith 1985a) reports an average reduction in diameter of carbonized seeds to be 5%. These experiments concur with Smith's results, Figure 1.

Two hundred seeds of each of the five varieties were measured for a total of 1000 modern seeds. 999 modern charred seeds were then measured (one was lost in the charring process). The average maximum diameter before carbonization is 1.74 mm. The average maximum diameter of the same seeds after carbonization is 1.653 mm. The difference between the two averages is 0.09 mm which is 5.2% of the maximum diameter before charring (1.74 mm).

SELECTION OF ARCHAEOLOGICAL SAMPLES

The next step in the investigation involved measuring *Chenopodium* fruits recovered from archaeological contexts in South America. Four sites were chosen, all of which are located in the Peruvian province of Junin. This study focussed on two of the sites: Panaulauca Cave and Pancan.

Panaulauca Cave was excavated by John W. Rick of Stanford University. It is a limestone rockshelter located at 4150 meters elevation above the puna and Lake Junin. Initial occupation is dated to 7700 bc and the uppermost intact layer is dated to ad 1200. (Pearsall 1989) Dr. Deborah Pearsall of the University of Missouri-Columbia directed the paleoethnobotanical research at this site and supplied carbonized *Chenopodium* from Panaulauca Cave for this investigation.

The site of Pancan is located in the Mantaro Valley in the central sierra of Peru between the Cordillera Occidental and Oriental on the shores of Laguna Paca at 3470 meters. There are three distinct levels of occupation. Level IV is the lowest level of occupation that has been extensively excavated dating from A.D. 550-650. Level III dates from A.D. 650-1000 and Level I dates from A.D. 1000-1350. The archaeological excavation and the paleoethnobotanical research was directed by Dr. Christine Hastorf of the University of Minnesota. Though lower stratigraphic levels at Pancan were not fully excavated, test pits were dug and *Chenopodium* seeds were extracted. Some of the *Chenopodium* seeds themselves were sent for accelerator carbon

dating to Simon-Fraser University. The lowest levels from this test pit have been dated to A.D. 365.

Because of the early occupation at the Panaulauca site, emphasis was given to the lowest levels which yielded *Chenopodium* seeds. Levels dating later than approximately 700 B. C. from Panaulauca were not used in this study. Instead, seeds from two additional excavations in the Mantaro Valley were incorporated into the analysis. These two sites are San Juan Pata and Tragadero Viejo. These two additional excavations were chosen for sampling because carbonized *Chenopodium* seeds from both sites have also been accelerator carbon dated by Simon-Fraser University.

Tragadero Viejo is located in the Yanamarca Valley near Lake Tragadero about 3 km from the modern town of Jauja. Seeds from this site used in this investigation date to A.D. 400. The second site, San Juan Pata is also in the Mantaro Valley above the town of Jauja. Seeds from this site have been accelerator dated to 940 B.C.

The site most extensively sampled was Pancan. There, levels IV, III and I were carefully sampled to include areas of domestic habitation. Proveniences such as domestic hearths, domestic structures and middens in occupation zones were chosen to extract whole *Chenopodium* seeds. Proveniences such as middens used as fill or cultural fill were not used. From the test pit and the other sites used in this analysis such precise use of cultural provenience was not possible.

Once the archaeological *Chenopodium* samples were chosen their maximum diameters were measured and recorded, Figure 4. The

goal was to have a total of 200 seed measurements from each level in each site though there were not always 200 seeds available from every level. Table 1 lists the site of origin, levels within sites, number of seeds measured, and the date of the phase.

ESTABLISHING PHASES

Ten separate phases were established from the available ancient *Chenopodium* samples. This was done to insure a chronological sequence between the two separate geographic areas of Pancan and Panaulauca. The earliest phases, 10-7, are from the site of Panaulauca. Phase 10 dates to approximately 3000 B.C. and includes levels 26 and 34. Phases 9, 8 and 7 coincide with Rick's phases 4-6 (Pearsall 1989). Phase 9 dates to approximately 2000 B.C. and includes levels 20, 21 and 22. Phase 8 includes only level 16 preceramic and dates to 1620 B.C. Level 16 preceramic is the earliest level which has an abundant occurrence of *Chenopodium* seeds (Pearsall 1989). Level 16 preceramic marks the end of the preceramic period. Phase 7 also dates to 1620 B.C. but signals the beginning of the ceramic period. Phase 7 includes levels 14, 15 and 16 ceramic.

Phase 6 seeds date to 940 B.C. All seeds in this sample are from the site of San Juan Pata. By including seeds recovered from San Juan Pata a temporal link was made between the two geographic areas of Pancan and Panaulauca. San Juan Pata dates a few hundred years earlier than Panaulauca level 11 which is the uppermost level from Panaulauca used in this analysis.

Phase 5 dates to approximately 300 b.c. and includes level

11 from Panaulauca. The site of Panaulauca is the earliest and most extensive temporal site spanning a time period of three millennia. Though there are few significant gaps between the lower levels of occupation which yielded whole *Chenopodium* seeds for analysis, the abundance of early preceramic seeds is small.

Phase 4 includes seed samples taken from the sites of Tragadero Viejo and test pits excavated at Pancan. Phase 4 dates from A.D. 365 to 400.

Phases 3, 2 and 1 are all from the site of Pancan and their dates consecutively span the period from A.D. 550 to 1300.

ANALYSIS OF TESTA THICKNESS

The second method of analysis used to determine the domesticated status of prehistoric *Chenopodium* was to measure and compare seed testa thickness of the archaeological samples with the testa thickness of modern charred *Chenopodium* seeds. (Smith 1985a.)

From investigations carried out by Dr. Bruce Smith of the Smithsonian Institution on North American *Chenopodium* of the eastern United States, domesticated types of *Chenopodium* have a greatly reduced testa thickness compared to wild types (Smith 1984, 1985, 1985a, 1987, 1987a, 1989, Fritz and Smith 1988, Smith and Cowan 1987. See also Wilson 1980). From his studies, Smith found that the most sensitive morphological indicator of *Chenopodium* domestication in North America is the loss or reduction in thickness of the outer epiderm, or testa. Mechanisms such as the thick testa within the wild populations of *Chenopodium* function to prohibit the premature germination of

mature seeds as well as restricting uniformity in germination. Thick testas also protect the seed from damage due to frost and insects and serve to protect the wild population in the event of severe drought. In such condition, the seed can lie dormant in the soil for one or more growing seasons. When the growing conditions improve the dormant wild fruit can then germinate thus preserving the survivability of the species (Harlan 1975). Testa thickness seems to be the first characteristic to be relaxed by human intervention.

Seed testa thickness was measured by using a Philips model scanning electron microscope (SEM) housed in the Plant Physiology Department of the University of Minnesota. Because of time and expense limitations a smaller sample size was analyzed to measure seed testa thickness. When possible 20 prehistoric seeds from each occupational level within sites was looked at. For comparison, 20 seeds from each of the carbonized modern varieties were scanned with the microscope. (Uncarbonized modern seed coats were not analyzed using SEM.) There is no evidence of change in testa thickness due to carbonization.

Table II lists each site, the levels sampled within each site, the number of testas measured from each site and each level, mean, minimum and maximum testa thickness, and the standard deviation.

The carbonized seeds were split in half under a light microscope using a sharp razor blade. One half of each seed was then mounted on an aluminum stub which had been covered with double-sided cellophane tape. The stub surface was then painted

with colloidal graphite which has adhesive qualities as well as conducting electricity. Then each stub was coated with gold palladium in a vacuum evaporator. (Smith 1988.)

Once in the microscope, the seed coat thickness could be measured. Usually a magnification of 640 times was sufficient to see and measure the seed coat in detail. The measurement can be taken from a micrograph of the seed or directly from the SEM photo monitor. Actual size calculations from electron micrographs can be converted into microns by using the following formula:

$$\text{Size in Microns} = \frac{\text{Measured Size on Micrograph in Centimeters} \times 10^4}{\text{Magnification}}$$

(One micron equals one thousandth of a millimeter.)

RESULTS

The two domesticated *C. quinoa* varieties, Jauja and Bolivian, can be discerned from the two wild species, quita and paiko, by comparison of maximum diameters, Figure 2. The Jauja variety of *C. quinoa* and the Bolivian variety of *C. quinoa* are much larger than the domesticate canihua and the two wild types; quita and paiko. What becomes problematic in discerning domestication by maximum diameter alone is that the domesticated variety of canihua has an actual mean diameter smaller than the wild variety quita. Note, however, that there are no wild seeds larger than 1.875 mm so a modern seed greater than 2mm will be domesticated, and must also be *C. quinoa* of the Bolivian or Jauja

varieties.

Figure 3 shows the frequency distribution of modern seed diameters measured. It is possible to distinguish seed types within certain frequency ranges. Wild paiko seeds do not exceed a maximum diameter much larger than 1 mm and are generally confined to the left hand bar of the histogram. Domesticated canihua overlaps in seed size with paiko and spans the first three bars of the histogram. Canihua reaches a maximum diameter of 1.4 mm. The problem arises when quita quinoa, the largest of the modern wild species is included. Quita diameter size spans 1.3 mm to 1.8 mm thus overlapping with the two largest domesticated varieties of *C. quinoa*; Jauja and Bolivian as well as small domesticated canihua. Jauja maximum diameter spans 1.4 to 2.8 mm and Bolivian maximum diameter covers 1.65 to 3.1 mm.

One noticeable characteristic of Figure 3 is its tri-modality. The vast majority of the two largest domesticates, Jauja and Bolivian, fall within the range greater than 1.9 mm (which is also the upper limit in maximum seed diameter for modern wild seeds) with the largest group near 2.2 mm - 2.3 mm. Indeed the mean diameter of Jauja is 2.2 mm and the mean diameter for Bolivian is 2.3 mm. These two domesticates, however, have the largest standard deviation. Standard deviation for Jauja = 2.175. Standard deviation for Bolivian = 2.349. Quita, with a much smaller range falls between 1.4 mm and 1.6 mm. The mean diameter for quita is 1.59 and the standard deviation is only 0.089. The third modality could actually be split into two sub-modalities of domesticated canihua and wild paiko. Paiko has the smallest deviation of only 0.079 and its mean diameter is 0.992 mm which

would indicate that the majority of seeds in this variety fall into the first or far left bar on the chart. The second part of this modality would be those seeds that fall within 1 mm and 1.4 mm. Most of these would no doubt be the small domesticate, canihua, whose mean diameter is 1.156 mm, standard deviation = 1.156

In summary, the greatest mean difference in maximum diameter of modern *Chenopodium* varieties lies between the Bolivian domesticate and wild paiko. The most similar types are wild paiko and domesticated canihua. Though Bolivian domesticated *C. quinoa* is easily distinguished from wild paiko by diameter alone, the maximum diameters for the other types of *Chenopodium* overlap considerably making the distinction between domesticates and wild varieties difficult unless testa thickness is also used in the comparison.

When data for maximum diameter of modern seeds is compared to the frequency distribution of maximum diameters of ancient seeds, Figure 4, we see that the majority of the ancient seeds fall within the ranges of modern quita quinoa and canihua though many also fall into the range of small Jauja domesticated types. (Jauja domesticates are as small as 1.4 mm.) There are very few that fall within the range larger than 1.9 mm which is the upper limit of seed diameter for modern wild species. Most seeds in the archaeological record do not reach the large size of their modern descendants. This is not to say that there are few domesticated seeds to be found in the archaeological record. Instead it implies that seed size has increased over the millennia.

Figure 4 also represents a smooth progression without the disparate modalities so obvious in Figure 3. This smooth progression seems to indicate that a more homogeneous seed population was being exploited rather than a combination of wild and domesticated species.

The difference between ancient and modern seed diameters is illustrated in Figures 5 and 6. Though the range in maximum diameters among the different modern groups overlaps, the ancient seeds tend to be more uniform in size as well as being somewhat smaller. This is similar to the range in maximum diameter of domesticated canihua and the wild species as illustrated in Figure 2. The ancient seeds, being more closely related in time to wild types reflect the uniformity in size inherent in the wild populations.

Though there are problems involved in discriminating between prehistoric wild and domesticated seeds and modern wild and domesticated seeds, it is true that there are no modern wild seeds larger than 1.9 mm. There are also very few prehistoric seeds which exceed 1.9 mm. This boundary cannot be used universally to distinguish wild from domesticated populations of *Chenopodium* because it excludes entirely the small domesticated canihua whose mean diameter is 1.156 mm. Canihua, when described by seed size, has little in common with the modern domesticated species of *Chenopodium quinoa* but is very similar in size to modern wild species. It is quite possible that a small domesticated seed similar in size to canihua was exploited by ancient populations in South America.

Modern *Chenopodium quinoa* does not appear to have a

counterpart in the archaeological record. Modern *C. quinoa* is much larger than most prehistoric seeds. This supports the idea that larger seed size is selected for but the change in diameter is minute and more slowly accomplished and therefore not a reliable morphological indicator of domestication among ancient populations.

A far more precise method of determining the domesticated status of *Chenopodium* is to measure the seed testa thickness. Figure 7 clearly delineates between the three modern domesticated varieties and the two modern wild types with minimal overlapping. The three modern domesticates display far more uniformity in testa thickness than the two modern wild species. This is to be expected as domesticated varieties do not need to rely on a thick testa to protect them from infestation or inclement weather situations. Wild species, however, need the thick protective outer coat if they are to survive in such harsh environments such as the Junin puna.

The overlap in range of testa thickness for modern wild and domesticated fruits is between 15 and 20 microns (μ). Those that do fall in this range are only a small portion of either wild or domesticated populations.

By comparing mean testa thickness of the five modern types of *Chenopodium* we see again that canihua displays a bit of both wild and domesticated morphological characteristics. Though it is a small seed, imitating modern wild types, it is also the domesticate with the thickest mean testa size. But the mean testa thickness for modern domesticated canihua does not overlap with

the wild species and is much more similar to the mean testa thickness of modern domesticated types. (Bolivian mean testa thickness =8.1 mu, Jauja mean testa thickness = 9.7 mu, canihua mean testa thickness =14.5 mu, quita mean testa thickness =38.4 mu, and paiko mean testa thickness =40.5 mu.)

Another conclusive argument as to the reliability of testa thickness in determining domesticated *Chenopodium* is the fact that there is a significant difference between canihua and paiko. This was not evident when using maximum diameter alone, Figure 2, in fact the two were very difficult to discern.

Figure 8 reveals the relationship between testa thickness and seed diameter among modern species. Using this analysis it is possible to distinguish which cluster belongs to which type of modern seed. Those with the smallest diameters and the thickest testa are paiko. Those with the smallest diameter and thin testa are canihua. Those which have a somewhat enlarged diameter and somewhat thicker testa are quita and the remainder with thin testa and large diameter are the Jauja and Bolivian varieties.

The relationship between testa thickness and seed diameter among ancient seeds is less distinguished as is shown in Figure 9. It is apparent, however, that the mean testa thickness for the prehistoric samples falls below 26 mu and most range between 10 mu and 15 mu, well within the bounds of domestication and very similar to the mean testa thickness of modern canihua. Also revealing in Figure 9 are the few small ancient seeds which have a thin testa. One problem with Figure 9 is that the temporal range of these ancient seeds spans more than 4 millennia.

Figure 10 shows the frequency distribution of ancient testa

thickness. 162 of the 183 ancient seed testas measured have thin testas. Roughly, one seventh of the prehistoric seeds appear to have a thick testa and could be considered wild. From this analysis it appears that *Chenopodium* domestication had occurred prior 3000 B.C., the earliest date available in this analysis.

Figure 11 describes the change in diameter over time of ancient seeds. It seems that seed size does increase over time but more seeds from the preceramic period need to be examined before actual change in size can be determined.

Figure 12 illustrates change in testa thickness of ancient seeds over time. Note that the earliest seed measured exhibits a thin testa. The line of regression on the chart indicates that seed coat thickness increases over time. This again is probably due to the lack of preceramic seeds available for analysis.

CONCLUSIONS

By comparing maximum diameters of modern domesticated types of *Chenopodium quinoa* and *Chenopodium pallidicaule*, canihua, to modern wild species *Chenopodium salinium*, quita, and *Chenopodium ambrosioides*, paiko, we have found that it is difficult to discern whether a seed type falls into a category of domesticated status or wild status by analysis of seed diameter alone. *C. quinoa* is larger than either of the two modern wild species but *C. pallidicaule*, canihua, is a small domesticate which can easily be confused with small wild species. Also, domesticated *C. quinoa* has a wide range of variation, especially the Jauja type, and some of these domesticated seeds are similar in size to modern

wild species, particularly that of *C. salinium*, quita.

Among modern seed varieties, there are no wild seeds which exceed a maximum diameter of 1.9 mm. Modern seeds larger than 1.9 mm are domesticated *C. quinoa* but, there are very few prehistoric seeds which reach this size. Yet a majority of the ancient *Chenopodium* population appears to be domesticated by testa thickness. Maximum diameter is not a reliable morphological indicator of domestication within ancient populations of *Chenopodium*.

From this study we have found that a very reliable morphological indicator of domestication among both modern populations of *Chenopodium* and ancient populations of *Chenopodium* is comparison of testa thickness.

Testas of domesticated *Chenopodium* range in thickness from 0 μ to about 28 μ . Testa thickness of wild *Chenopodium* range from about 15 μ to as much as 80 μ . It is to be expected that a percentage of the wild population would have characteristics similar to domesticated populations. These thin testa characteristics of the wild population blossomed and adapted to human intervention. Segments of the wild populations which exhibited thin testas were selected for by humans and a domesticated thin testa plant population of *Chenopodium* was developed.

We have also found that *Chenopodium* was domesticated prior to 3000 B.C. This date is one thousand years earlier than other published estimates of domestication of *Chenopodium* in South America (Pearsall 1989). Though the seed size remained small among these early prehistoric seeds, the testa thickness had

already reached the range in testa thickness of modern domesticated types of *Chenopodium*.

Testa thickness was more swiftly relaxed among ancient seed populations than increases in diameter were attained.

It is still not known when *Chenopodium* was initially domesticated. Nor do we know how long the process took. Is testa thickness relaxed in a matter of a few generations? Or, does it take hundreds of years? Recovery and analysis of more preceramic *Chenopodium* seeds from the Andes are needed before these questions can be answered.

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Maximum seed diameters before and after carbonization

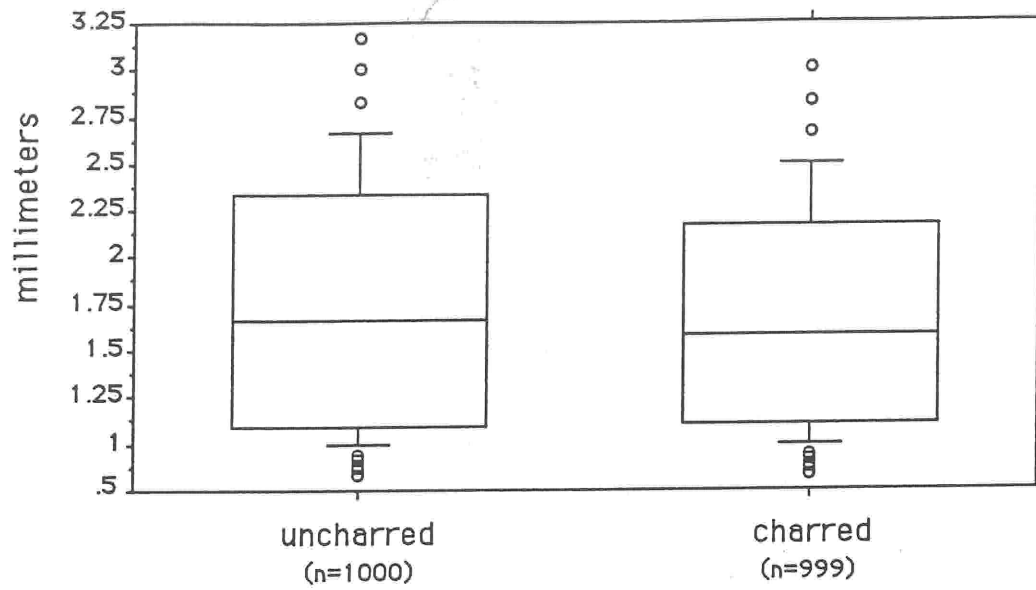


Fig. 1. Average maximum diameter before carbonization is 1.74 mm. Average maximum diameter after carbonization is 1.65 mm.

Comparison of modern charred seed diameters

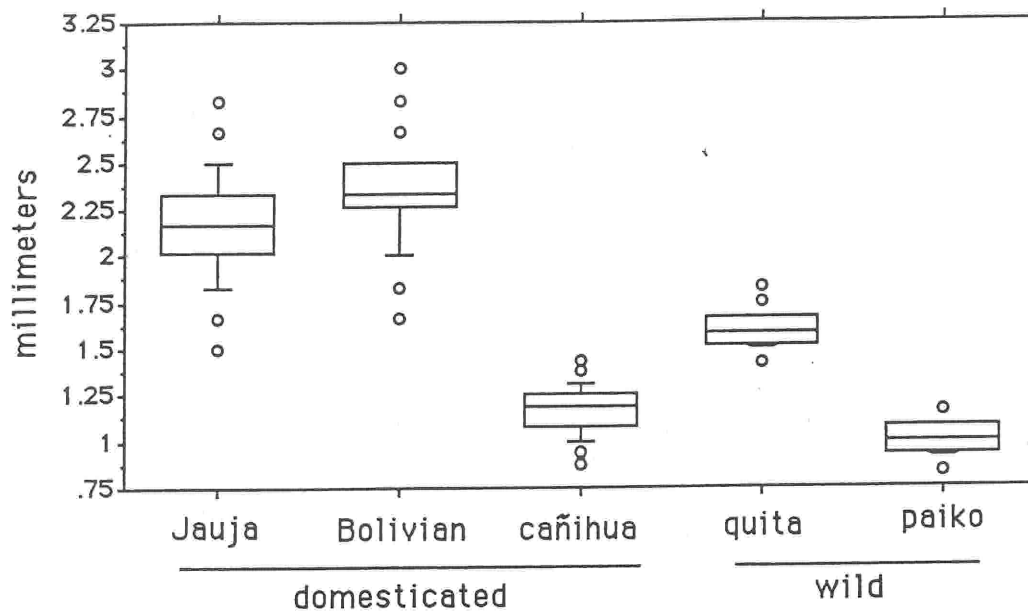


Fig. 2. The Jauja and Bolivian domesticates are much larger in diameter than domesticated cañihua and both wild species of modern *Chenopodium*. No wild seeds exceed 1.9 mm but the range in diameter of domesticated seeds overlaps entirely the range in diameter for modern wild seeds. (n=199 seeds for each group.)

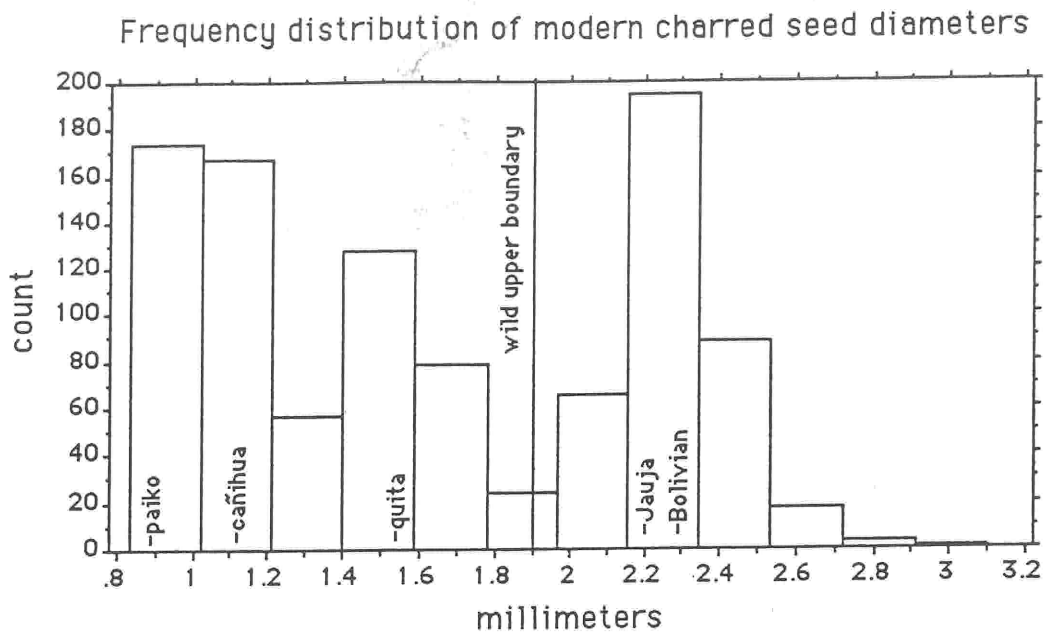


Fig. 3. Mean diameter for each species corresponds to the tri-modal configuration of the histogram. Note that there are no modern wild seeds larger than 1.9 mm. (n=200 for each group.)

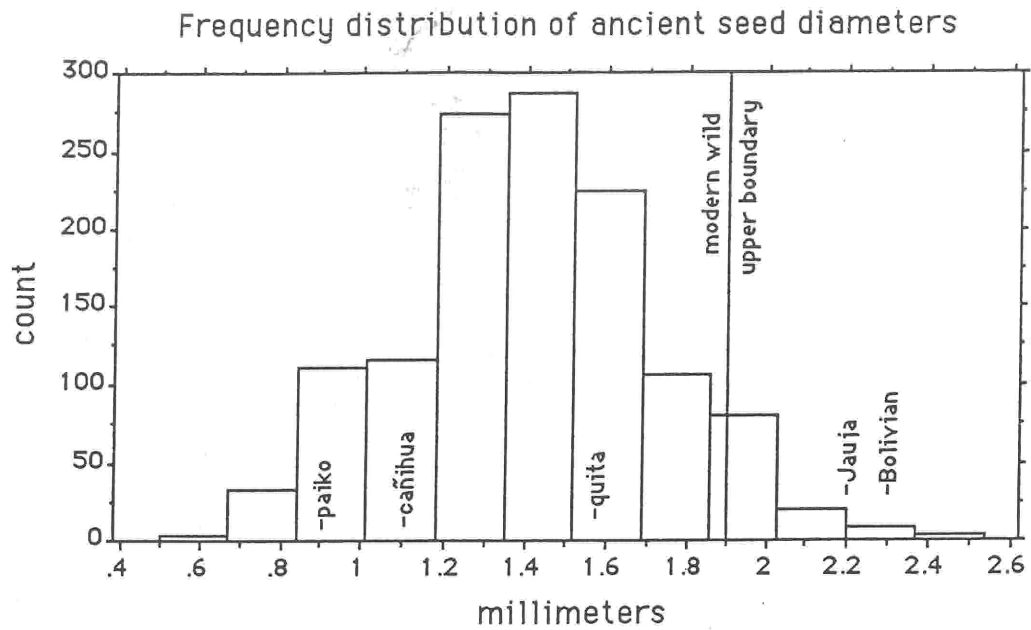


Fig. 4. Mean diameters for modern varieties are included. Also note the modern wild upper boundary at 1.9 mm. (Total ancient seeds measured = 1267.)

Comparison of ancient and modern seed diameters

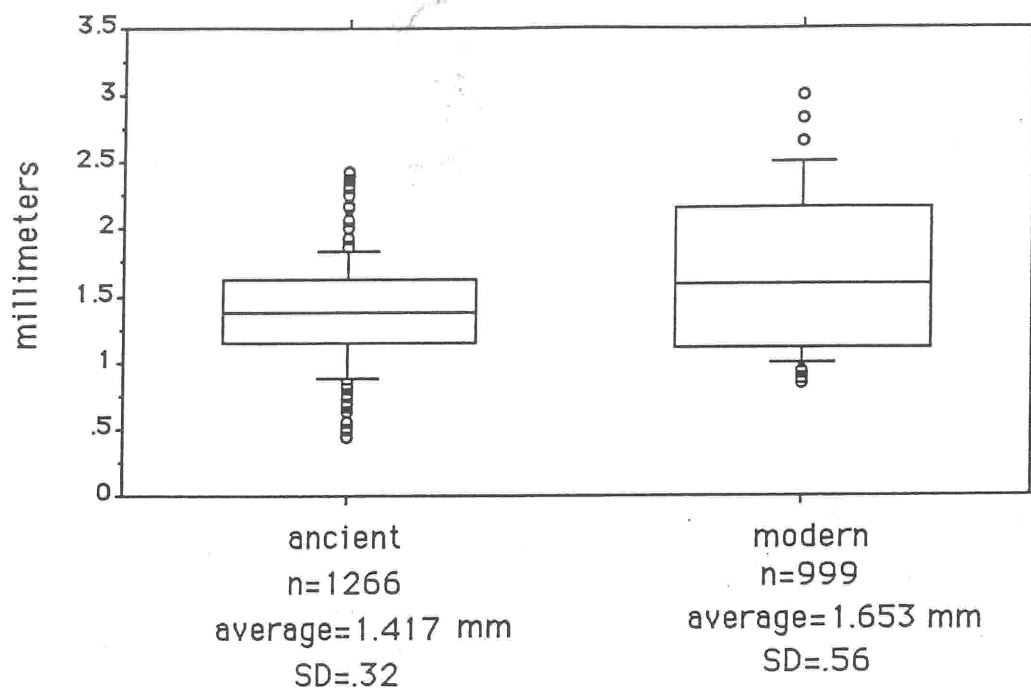


Fig. 5. Illustrates the considerable overlap in seed size between ancient populations and modern species. The ancient seeds tend to be more uniform in size and slightly smaller than modern species.

Comparison of ancient seed diameters with modern wild seed diameters and modern domesticated seed diameters

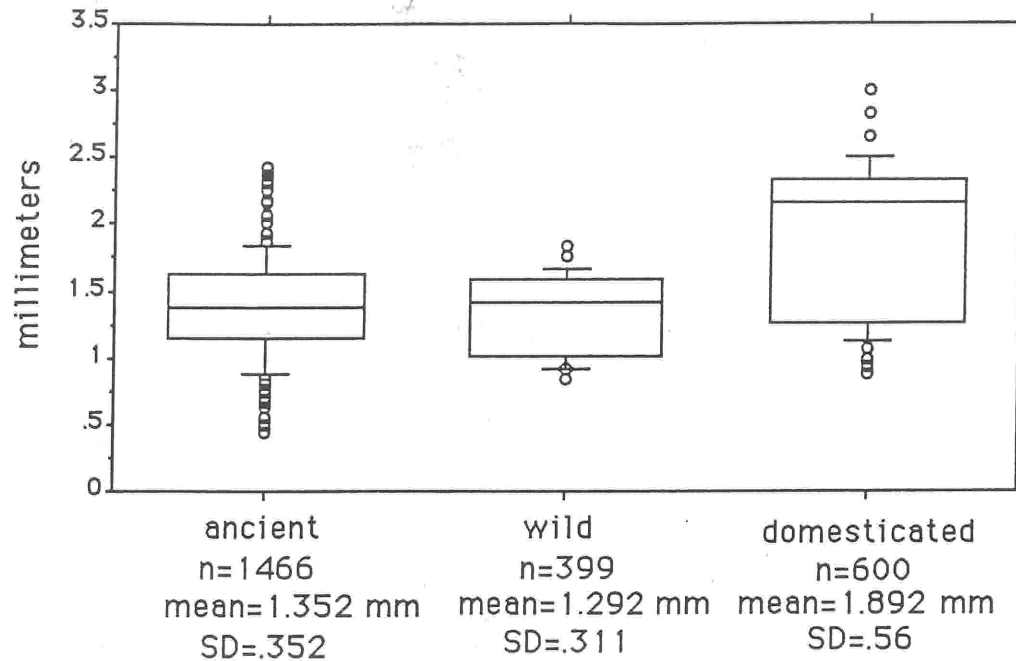


Fig. 6. The mean diameter for ancient seeds is only .067 mm larger than modern wild seeds. The modern domesticate mean diameter is .733 mm larger than the ancient mean diameter. This would seem to indicate that ancient seeds are probably wild. When testa thickness is compared between ancient and modern domesticated seed populations this conclusion proves false. All modern seeds are carbonized.

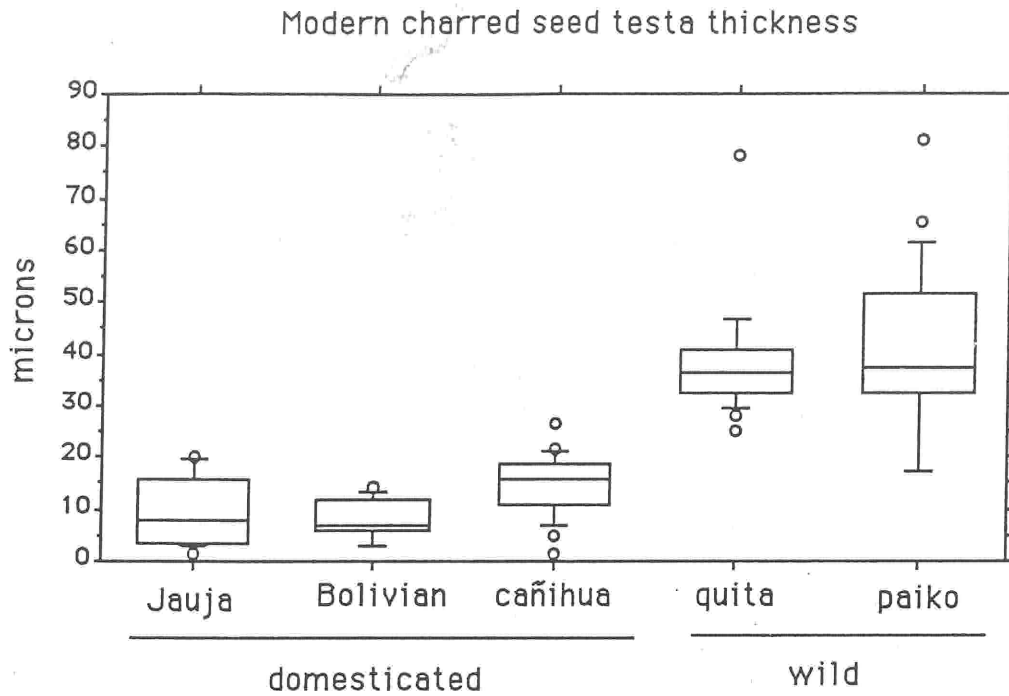


Fig. 7. There is a clear differentiation when testa thickness is compared between modern domesticates and modern wild species. (n=20 for each group.)

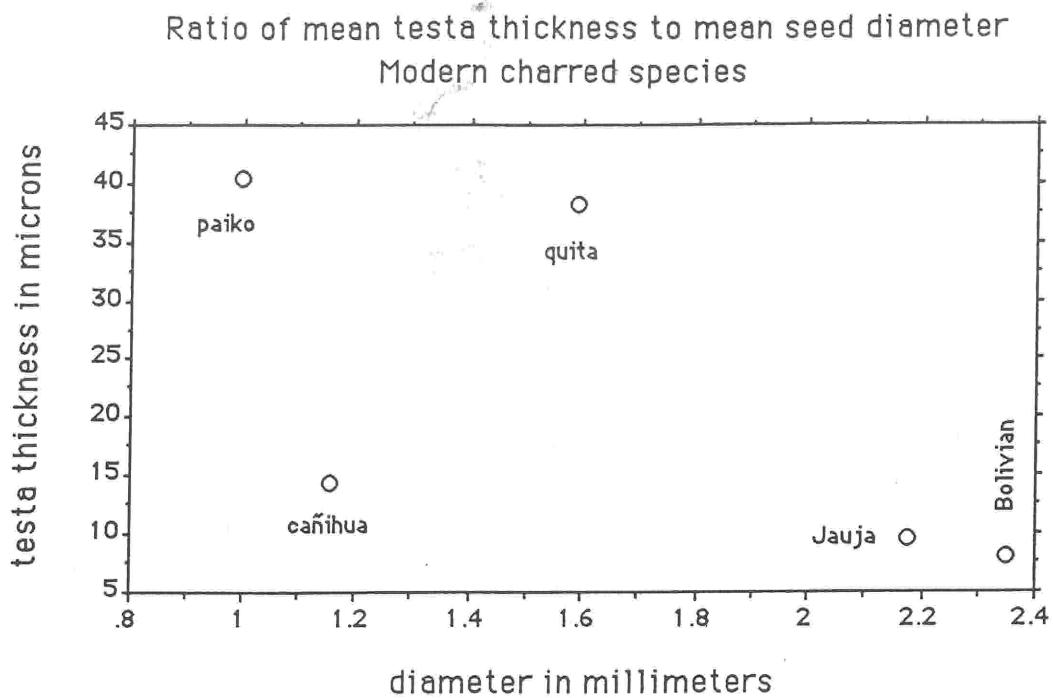


Fig. 8. Illustrates the relationship between testa thickness and seed diameter among modern wild and domesticated populations. The units of the ratio are microns/millimeters. Millimeter measurements were averaged over the entire sample size of 200.

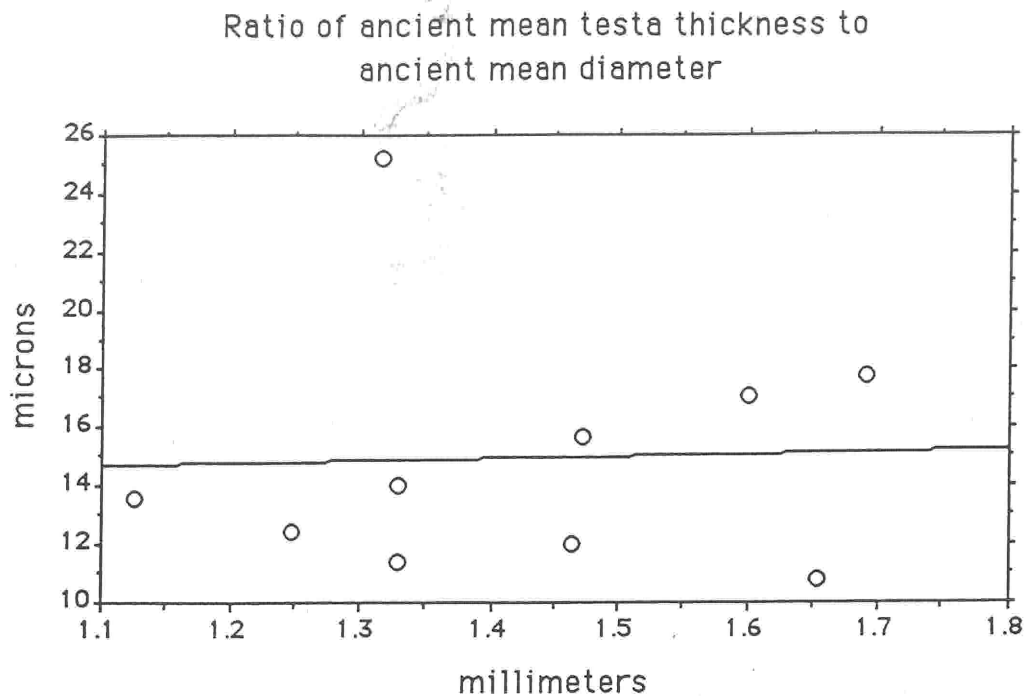


Fig. 9. Illustrates the ratio between ancient mean testa thickness to the ancient mean seed diameters. There appears to be only a slight correlation between seed size and level of domestication, even the smallest seeds have a thin testa. Ratios between mean testa thickness and mean seed diameter were made using only those levels which had 10 or more measurements for testa thickness. Therefore, not included are Pancan 25 and Panaulauca levels 14, 15, 22 and 34. Due to differences in sample size the line of regression should not be interpreted quantitatively. ($r = .032$.)

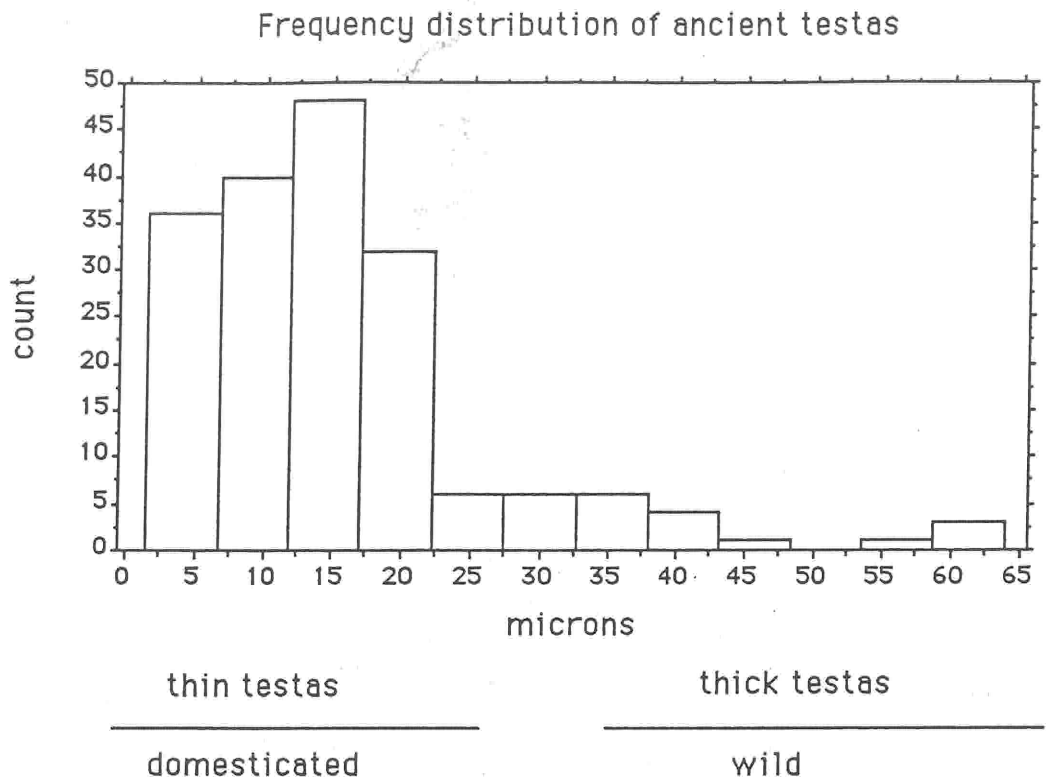


Fig. 10. A vast majority of the ancient seeds exhibit a thin testa which is a morphological indicator of domestication. Total number of ancient seed testas measured=183. Only 21 seeds fall into the last seven bars of the histogram on the right. 162 seeds fall into the first five bars on the left. Roughly one seventh of the seeds in the ancient population can be considered wild by comparison of testa thickness.

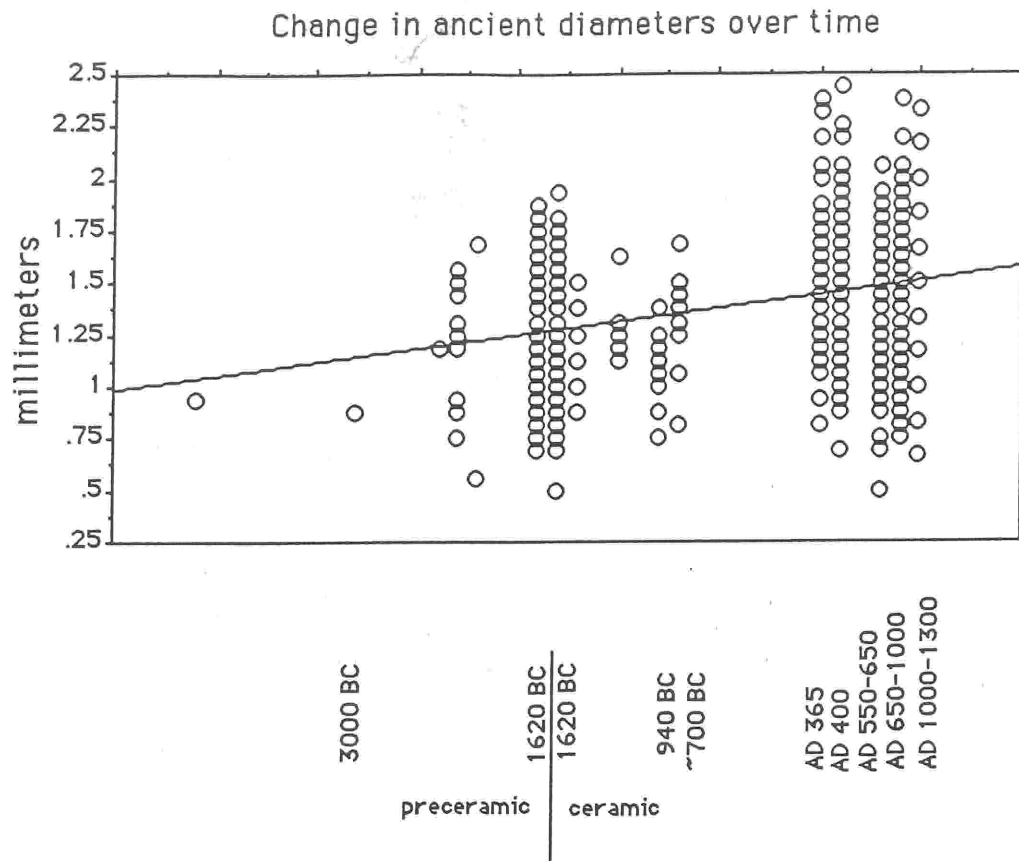


Fig. 11. Indicates that ancient seed size does increase over time. More preceramic seeds are needed to prove this trend. (n=1277, r= .317.)

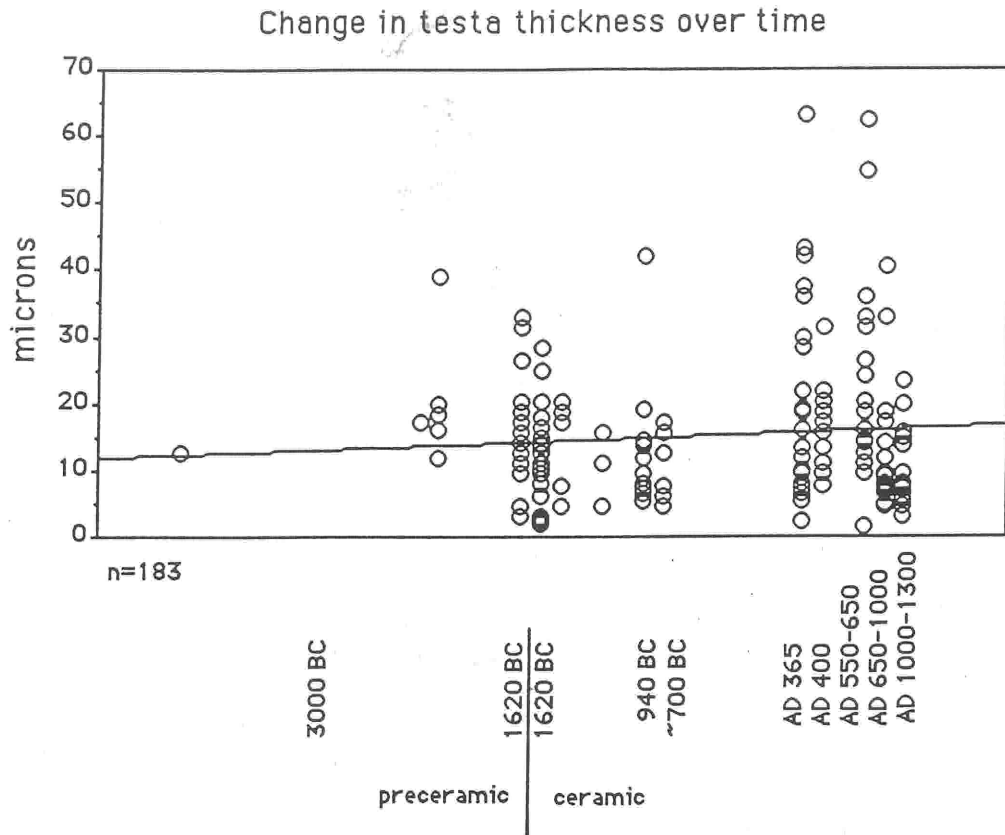


Fig. 12. describes the change in testa thickness over time. There appears to be a slight thickening of testa thickness over time but this is probably a result of so few preceramic seeds available for measurement. From this illustration it appears that *Chenopodium* was domesticated prior to 3000 BC. ($r = .084$.)

TABLE 1

NUMBER OF ANCIENT SEED DIAMETERS MEASURED

PHASE	APPROXIMATE DATE	COUNT	SITE	LEVEL
1	A.D. 1000-1300	200	PANCAN	I
2	A.D. 650-1000	200	PANCAN	III
3	A.D. 550-650	200	PANCAN	IV
4	A.D. 400	200	TRAGADERO VIEJO	-
4	A.D. 365	12	PANCAN (TEST PIT)	25
4	A.D. 365	50	PANCAN (TEST PIT)	26-27
5	~700 B.C.	11	PANAULAUCA	11
6	940 B.C.	12	SAN JUAN PATA	-
7	-	7	PANAULAUCA	14
7	-	9	PANAULAUCA	15
7	1620 B.C.	200	PANAULAUCA	16 CERAMIC
8	1620 B.C.	150	PANAULAUCA	16 PRECERAMIC
9	-	2	PANAULAUCA	20
9	-	10	PANAULAUCA	21
9	-	1	PANAULAUCA	22
10	~3000 B.C.	1	PANAULAUCA	26
10	-	1	PANAULAUCA	34

TABLE II
NUMBER OF ANCIENT SEED TESTAS MEASURED

PHASE	SITE	LEVEL	COUNT	MEAN	MIN	MAX	SD
1	PANCAN	I	18	10.8	3.1	23.4	6.6
2	PANCAN	III	21	12.0	4.7	40.6*	2.0
3	PANCAN	IV	20	5.2	1.6	62.5*	17.2
4	TRAGADERO VIEJO	-	14	15.7	7.812	31.25*	31.3
4	PANCAN	25	9	22.1	8.0	42.2*	11.8
4	PANCAN	26-27	17	17.1	2.2	63.0*	16.5
5	PANAULAUCA	11	10	11.4	4.7	17.2	5.1
6	SAN JUAN PATA	-	11	13.6	5.2	42.2*	10.3
7	PANAULAUCA	14	3	10.4	4.7	15.6	5.5
7	PANAULAUCA	15	5	13.8	4.7	20.3	7.0
7	PANAULAUCA	16 CERAMIC	22	12.5	2.0	28.1	7.0
8	PANAULAUCA	16 PRECERAMIC	21	14.0	3.1	32.8*	8.4
9	PANAULAUCA	20	-	-	-	-	-
9	PANAULAUCA	21	10	17.7	12.0	39.0*	8.0
9	PANAULAUCA	22	1	17.2	-	-	-
10	PANAULAUCA	26	-	-	-	-	-
10	PANAULAUCA	34	1	12.5	-	-	-

* Wild seeds have a testa thickness > 28 mu.